Design of Stirling Inertance Tube Pulse Tube Cryocooler for Cooling Infrared Sensors

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Abstract— Pulse tube cryocooler (PTCC) is popular now a day in Space Industry due to no moving parts at the cold end of it. The main attraction of pulse tube cryocooler is long life, reliability, less cost and smaller size due to absence of valves. PTCC is using for cooling infrared sensors and cameras. PTCC has less vibration comparatively to Stirling Cryocooler and due to it, we can get clearer picture from IR cameras. Here I will discuss PTCC of 1W heat capacity at 80K for IR sensor. Sage software is used for designing.

Key words: Pulse Tube Cryocooler (PTCC), Infrared Sensors

I. Introduction

Pulse tube cryocooler is widely used in space industry now a day. No moving part at the cold end is main attraction of it, because it reduces vibrations and improves the life of cryocooler. Due to this it is used for cooling Infrared sensors now a day. Pulse tube cryocooler mainly consists of pressure wave generator, aftercooler, Regenerator, cold heat exchanger, pulse tube, hot heat exchanger, inertance tube and reservoir. Inline Pulse tube cryocooler is shown in Fig1 with its main components. Various type of configurations are used in PTCC like inline, U type, Coaxial and Annular. PTCC is high frequency cryocooler which is generally operated at 60-100 Hz. For initial designing inline configuration is best because it has less pressure losses compared to other configuration. All the components are in line so the working gas has to oscillate only. Helium is used as working gas.

Various phase shift mechanisms are used to improve the improve the performance of PTCC like orifice type, double inlet type and inertance type. Inertance type phase shift mechanism gives the best cooling and we can get cooling at 80-100K. This is required temperature for cooling Infrared sensor.

Here first theoretical calculation is done based on approximate design calculation and then it is designed in Sage software. Sage software is widely used for designing various cryocoolers.

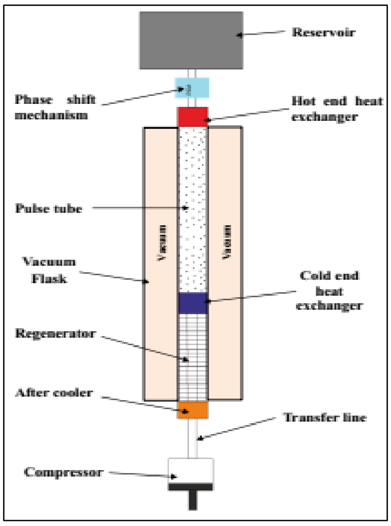

Fig. 1: Schematic of Inline Pulse Tube Cryocooler

The infrared waves typically have wavelengths between 0.75 and 1000µm. The wavelength region which ranges from 0.75 to 3µm is known as the near infrared regions. The region between 3 and 6µm is known as the mid-infrared and infrared radiation which has a wavelength greater higher than 6µm is known as far infrared.

II. Modeling of PTCC with Sage Software

Sage software is used for designing inertance tube pulse tube cryocooler. First some working parameters are selected according to our requirement which are shown below in table

Sr No.	Parameter	Unit	Value
1	Cooling capacity	W	1
2	Woking temperature	K	80
3	Hot end temperature	K	300
4	Working Pressure	Pa	2500000
5	Dynamic pressure	Pa	350000
6	Operating Frequency	Hz	60
7	Accoustic power at warm end	W	90

Table 1: Fixed Parameters of PTCC

Here regenerator and pulse tube material are titanium because it has good corrosion resistance property and good fracture resistance property at cryogenic temperature. For heat exchangers copper is used. Inertance tube and reservoir are made of SS304 material. Regenerator is filled with SS316 wire mesh (mesh number 400) and for heat exchangers copper wire mesh of 200 mesh size is used. This is suitable for 80-100K application. These all materials have good corrosion resistance property and good strength at cryogenic temperature

We assume isothermal (temperature is constant) process in regenerator and heat exchanger. Adiabatic process in pulse tube. Dual compressor is used to reduce the vibrations due to unbalancing. Linear motor with pressure wave generator is used.

In fig 2, root level component of inline PTCC using inertance tube as phase shift mechanism is shown. Here is pressure source at 25 bar and then two piston and two drivers are used because it's dual compressor. Then compression space and buffer space is connected to show compression space and extra space which is available in compressor. Here liner motor and pressure wave generator both work together and works as compressor.

Inline head is connected to compressor with connecting tube. Inline head components are shown in Fig3. There are mainly regenerator, pulse tube, inertance tube and reservoir. First there is main rejector which is directly connected to compressor with connecting tube, it is basically representing aftercooler. Its temperature is assumed as 300K (ambient condition). Next component is regenerator which is connected to acceptor. Here in regenerator, titanium is used as material and helium as working gas. Regenerator maintain 80K temperature and we used 400 mesh size. Then it is connected to acceptor which is maintained at 80K and this is working as cold heat exchanger. Here we attach our device which is to be cooled. Here we need cooling capacity 1W, so I maximize the cooling capacity.

Next component is acceptor transition, which signifies which is basically works as connector of cold heat exchanger and pulse tube because there diameters are different. Its simple tube. Pulse tube is connected to the acceptor transition and next to pulse tube, it is secondary rejecter which represents hot heat exchanger. In hot heat exchanger 200 mesh is used and material is SS316. It is connected to the inertance tube which is used to produce required phase shift. It is long tube with small diameter because inertance is directly proportional to length and inversely proportional to diameter of tube. Last component is reservoir.

III. CONCLUSION

Here we get all the dimensions of PTCC through SAGE and we get the required cooling capacity. Dimension of various components is listed in table 2.

SR. No.	Component	Value (mm)
1	Regenerator length	56
2	Regenerator diameter	15
3	Pulse tube length	60
4	Pulse tube diameter	8
5	Inertance tube length	2000
6	Inertance tube diameter	2

Table 2: Dimensions of Various Components

We compare all these dimensions with dimensions which we obtained through sage software. We get 2.67 W through SAGE and 1W through theoritical calculation at 80K. This must be validated experimentally. For this, it is planned to fabricate and demonstrate the high frequency pulse tube cryocooler.

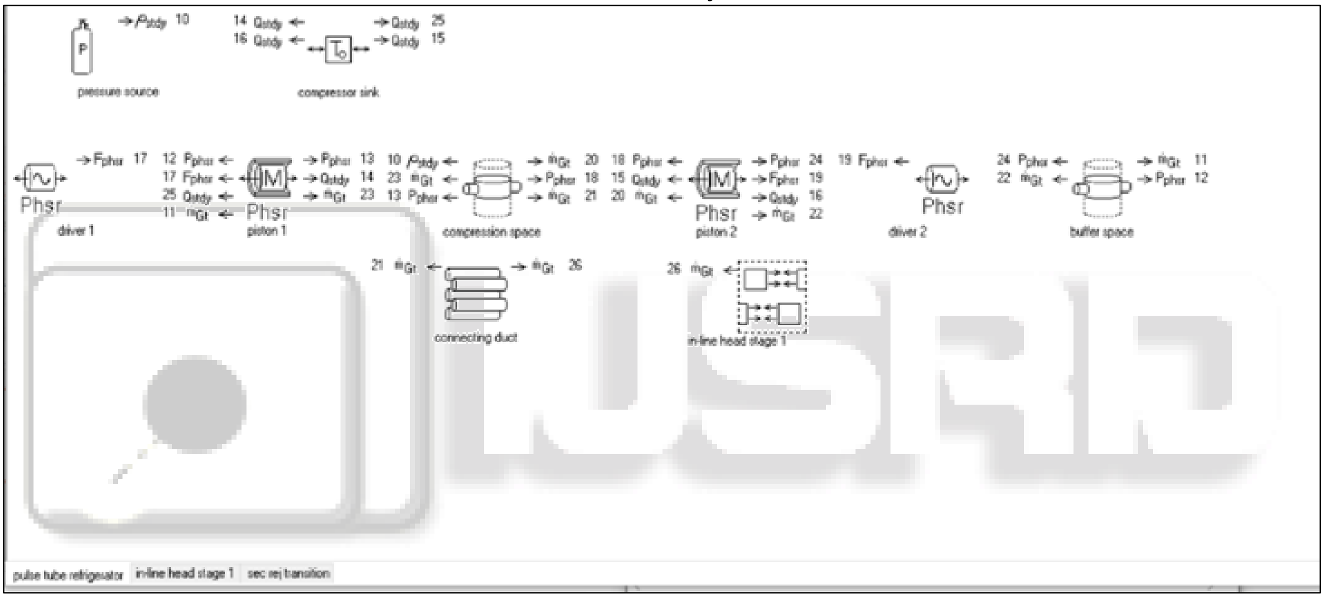

Fig. 2: Root level programming of inline PTCC

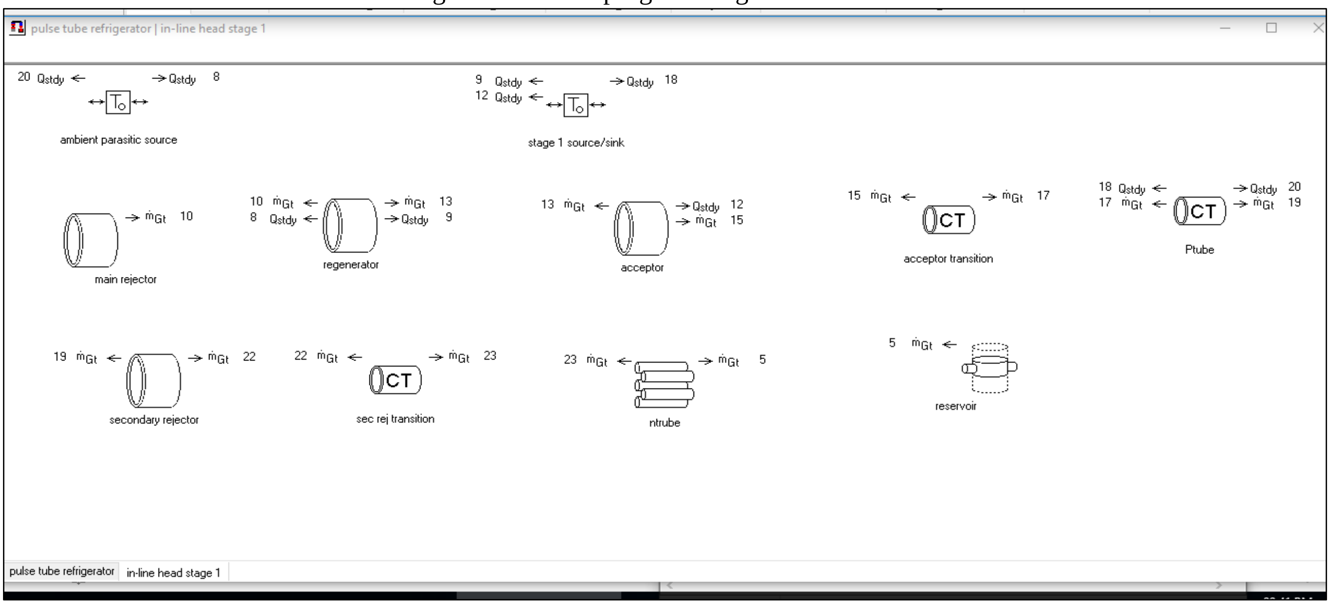

Fig. 3: Components of inline head stage 1

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REFERENCES

[1] T. Nast, J. Olson, P. Champagne, E. Roth, "Development of Micr6cryocoolers for Space and Avionics Applications", Cryocoolers 19, International Cryocooler Conference, Inc., Boulder, CO, 2016
[2] Haizheng Dang,"Development of high performance moving-coil linear compressors for space Stirling-type pulse tube cryocoolers", Cryogenics 68 (2015) 1–18
[3] Kranthi Kumar J, Jacob S, Karunanithi R, Narasimham G. S. V. L, Damu C, Praveen T.a, Samir M, "Improved performance of an indigenous Stirling type pulse tube cooler and pressure wave generator", 25th International Cryogenic Engineering Conference and the International Cryogenic Materials Conference in 2014, ICEC 25–ICMC 2014
[4] S. Jacob, R. Karunanithi, J. Kranthi Kumar, C. Damu, M. Achanur, G. Jagadish and A. S. Gour," Evaluation of mechanical losses in a linear motor pressure wave generator", Advances in Cryogenic Engineering, AIP Conf. Proc. 1434, 1226-1233 (2012)
[5] S.S. Li1, H.Z. Dang, Y.N. Wu,L.B. Wang, K.X. Yang, "Investigation on the Phase Characteristics of High Frequency Inertance Pulse Tube Cryocoolers above 50 K", Cryocoolers 16, International Cryocooler Conference, Inc., Boulder, CO,

